



## Decomposition Algorithm for Global Reachability on a Time-Varying Graph

This method sequentially solves a series of small problems instead of a single large problem.

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A decomposition algorithm has been developed for global reachability analysis on a space-time grid. By exploiting the upper block-triangular structure, the planning problem is decomposed into smaller subproblems, which is much more scalable than the original approach.

Recent studies have proposed the use of a hot-air (Montgolfier) balloon for possible exploration of Titan and Venus because these bodies have thick haze or cloud layers that limit the science return from an orbiter, and the atmospheres would provide enough buoyancy for balloons. One of the important questions that needs to be addressed is what surface locations the balloon can reach

from an initial location, and how long it would take. This is referred to as the global reachability problem, where the paths from starting locations to all possible target locations must be computed.

The balloon could be driven with its own actuation, but its actuation capability is fairly limited. It would be more efficient to take advantage of the wind field and "ride" the wind that is much stronger than what the actuator could produce. It is possible to pose the path planning problem as a graph search problem on a directed graph by discretizing the space-time world and the vehicle actuation.

The decomposition algorithm provides reachability analysis of a time-vary-

ing graph. Because the balloon only moves in the positive direction in time, the adjacency matrix of the graph can be represented with an upper block-triangular matrix, and this upper block-triangular structure can be exploited to decompose a large graph search problem. The new approach consumes a much smaller amount of memory, which also helps speed up the overall computation when the computing resource has a limited physical memory compared to the problem size.

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## Autonomous GN&C for Spacecraft Exploration of Comets and Asteroids

An integrated autonomous guidance, navigation, and control capability is developed for enabling precision small-body close-proximity operations and touch-and-go sampling.

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A spacecraft guidance, navigation, and control (GN&C) system is needed to enable a spacecraft to descend to a surface, take a sample using a touch-and-go (TAG) sampling approach, and then safely ascend. At the time of this reporting, a flyable GN&C system that can accomplish these goals is beyond state of the art. This article describes AutoGNC, which is a GN&C system capable of addressing these goals, which has recently been developed and demonstrated to a maturity TRL-5-plus.

The AutoGNC solution matures and integrates two previously existing JPL capabilities into a single unified GN&C system. The two capabilities are AutoNAV and G-REX. AutoNAV is JPL's current flight navigation system, and is fairly mature with respect to flybys and rendezvous with small bodies, but is lacking capability for close surface proximity operations, sampling,

and contact. G-REX is a suite of low-TRL algorithms and capabilities that enables spacecraft operations in close surface proximity and for performing sampling/contact. The development and integration of AutoNAV and G-REX components into AutoGNC provides a single, unified GN&C capability for addressing the autonomy, close-proximity, and sampling/contact aspects of small-body sample return missions.

AutoGNC is an integrated capability comprising elements that were developed separately. The main algorithms and component capabilities that have been matured and integrated are autonomy for near-surface operations, terrain-relative navigation (TRN), real-time image-based feedback guidance and control, and six degrees of freedom (6DOF) control of the TAG sampling event.

Autonomy is achieved based on an AutoGNC Executive written in Virtual Ma-

chine Language (VML) incorporating high-level control, data management, and fault protection. In descending to the surface, the AutoGNC system uses camera images to determine its position and velocity relative to the terrain. This capability for TRN leverages native capabilities of the original AutoNAV system, but required advancements that integrate the separate capabilities for shape modeling, state estimation, image rendering, defining a database of onboard maps, and performing real-time landmark recognition against the stored maps.

The ability to use images to guide the spacecraft requires the capability for image-based feedback control. In AutoGNC, navigation estimates are fed into an onboard guidance and control system that keeps the spacecraft guided along a desired path, as it descends towards its targeted landing or sampling

site. Once near the site, AutoGNC achieves a prescribed guidance condition for TAG sampling (position/orientation, velocity), and a prescribed force profile on the sampling end-effector. A dedicated 6DOF TAG control then implements the ascent burn while recovering from sampling disturbances and induced attitude rates. The control also minimizes structural interactions with flexible solar panels and disallows any

part of the spacecraft from making contact with the ground (other than the intended end-effector).

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*The software used in this innovation is available for commercial licensing. Please contact Daniel Broderick of the California Institute of Technology at danielb@caltech.edu. Refer to NPO-47250.*

## Efficient Web Services Policy Combination

**This algorithm serves as the basis for reliable, fast, and automatic network communications.**

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Large-scale Web security systems usually involve cooperation between domains with non-identical policies. The network management and Web communication software used by the different organizations presents a stumbling block. Many of the tools used by the various divisions do not have the ability to communicate network management data with each other. At best, this means that manual human intervention into the communication protocols used at various network routers and endpoints is required. Developing practical, sound, and automated ways to compose policies to bridge these differences is a long-standing problem. One of the key subtleties is the need to deal with inconsistencies and defaults where one organization proposes a rule on a particular feature, and another has a different rule or expresses no rule. A general approach is to assign priorities to rules and observe the rules with the highest priorities when there are conflicts.

The present methods have inherent inefficiency, which heavily restrict their practical applications. A new, efficient algorithm combines policies utilized for

Web services. The method is based on an algorithm that allows an automatic and scalable composition of security policies between multiple organizations. It is based on defeasible policy composition, a promising approach for finding conflicts and resolving priorities between rules.

In the general case, policy negotiation is an intractable problem. A promising method, suggested in the literature, is when policies are represented in defeasible logic, and composition is based on rules for non-monotonic inference. In this system, policy writers construct metapolicies describing both the policy that they wish to enforce and annotations describing their composition preferences. These annotations can indicate whether certain policy assertions are required by the policy writer or, if not, under what circumstances the policy writer is willing to compromise and allow other assertions to take precedence. Meta-policies are specified in defeasible logic, a computationally efficient non-monotonic logic developed to model human reasoning.

One drawback of this method is that at one point the algorithm starts an ex-

haustive search of all subsets of the set of conclusions of a defeasible theory. Although the propositional defeasible logic has linear complexity, the set of conclusions here may be large, especially in real-life practical cases. This phenomenon leads to an inefficient exponential explosion of complexity.

The current process of getting a Web security policy from combination of two meta-policies consists of two steps. The first is generating a new meta-policy that is a composition of the input meta-policies, and the second is mapping the meta-policy onto a security policy. The new algorithm avoids the exhaustive search in the current algorithm, and provides a security policy that matches all requirements of the involved meta-policies.

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*The software used in this innovation is available for commercial licensing. Please contact Daniel Broderick of the California Institute of Technology at danielb@caltech.edu. Refer to NPO-47279.*

## Using CTX Image Features to Predict HiRISE-Equivalent Rock Density

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Methods have been developed to quantitatively assess rock hazards at candidate landing sites with the aid of images from the HiRISE camera onboard NASA's Mars Reconnaissance Orbiter. HiRISE is able to resolve rocks as small as 1-m in di-

meter. Some sites of interest do not have adequate coverage with the highest resolution sensors and there is a need to infer relevant information (like site safety or underlying geomorphology). The proposed approach would make it possible

to obtain rock density estimates at a level close to or equal to those obtained from high-resolution sensors where individual rocks are discernable.

The low-resolution data considered here are CTX images, which have a